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NOTE ON THE DEGENERATIONS FOLLOWING DOUBLE TRANSVERSE, LONGITUDINAL, AND ANTERIOR CORNUAL LESIONS OF THE SPINAL CORD. By A. S. GRÜNBAUM, B.A.

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NOTE ON THE DEGENERATIONS FOLLOWING DOUBLE TRANSVERSE, LONGITUDINAL, AND ANTERIOR CORNUAL LESIONS OF THE SPINAL CORD. By ALBERT S. GRÜNBAUM, B.A., *Gonville and Caius College, Cambridge.* (Plate XIV.)

THE degenerative effects of simple section of the cord are now fairly well known. But there are various other possible injuries to the cord, the results of which have not been investigated. Some of these I propose to take into account in the following communication.

The double transverse divisions were done on monkeys and the longitudinal divisions and anterior cornual lesions on cats. The cord was laid bare in the required region and then divided :—transversely by blunt-pointed scissors, longitudinally with a Paget's knife, or the anterior cornu injured with a bent needle.

The chief difficulties are :—(1) to ensure that the second transverse division shall be complete. Owing to the retraction of the cord after the first division this is by no means easy. (2) In the longitudinal division, to find and keep to the middle line and to be sure of dividing the anterior commissure. Hæmorrhage rarely presents any difficulty unless the venous sinuses along the back of the vertebral bodies have been wounded.

Deep horsehair sutures were used for the muscles and the same material for the skin sutures. A collodion dressing was then applied. The stitches remained in for the whole time the animals were kept alive, except in the case of one cat. Either operation can be performed in 30—40 minutes from beginning to end. The animals were kept in a menagerie at a temperature between 70° F. and 80° F. Shock, as a whole, was conspicuous by its absence.

One operation also was done in which, as well as the double division of the cord, one of the posterior roots going to the isolated portion was cut, centrally to the ganglion, but the histological result was not obviously different from that of the others.

Notes on Cases.

CASE I. Macacus Rhesus ♀.

Nov. 18th, 1891. Double section of cord.

11 a.m. Temp. 101°·7 F. 1 p.m. Temp. 94°·4 F. Reflexes absent.

Nov. 19th. Takes solid food. Legs flushed and hot.

Nov. 21st. Temp. 101°·8 F. Tremors of legs. Tendon reflexes absent. Legs still warm.

Nov. 23rd. Tremors gone. Limbs cooler.

May 16th, 1892. Killed by chloroform. Tendon reflexes had not returned. Lesions found to be at level of 12th thoracic and 3rd lumbar nerve-roots respectively.

CASE II. M. Rhesus ♂.

Dec. 22nd, 1892. Operation as above. No apparent shock.

Dec. 25th. Animal quite well.

Jan. 7th, 1893. Knee-jerk has returned.

Jan. 18th. Killed by chloroform. Knee-jerks were somewhat exaggerated. Lesions between 9th and 10th thoracic and 12th thoracic and 1st lumbar nerve-roots.

CASE III. M. Rhesus ♀.

Sept. 22nd, 1893. Double complete division of cord and of posterior roots going to isolated portion on R. side. No apparent shock.

Sept. 26th. Knee-jerks present. Reflexes from toes also obtained.

Oct. 2nd. Monkey found dead in cage. No suppuration anywhere. One posterior root going to isolated piece on R. side had not been divided.

The lesion in each case isolated a piece of cord about two segments long in the lower thoracic region. In monkey I. the knee-jerk never returned: in monkey II. it reappeared after 16 days: in monkey III. already in four days which is, I believe, the shortest recorded interval.

CASE IV. Cat.

May 30th, 1893. Longitudinal division of cord, in lumbar region.

May 31st. Both knee-jerks present.

June 1st. Can jump up 4 feet (into cage).

June 20th. Killed by chloroform. Lesion is between 5th—6th lumbar nerve-roots.

CASE V. Cat.

July 26th, 1893. Longitudinal division in knee-jerk region.

Aug. 16th. Killed. Lesion about level of the 6th lumbar nerve-root.

In both these cases the knee-jerk was unaffected by the lesion.

The three cats in which the left anterior cornu in the lumbar enlargement was injured were allowed to live about three weeks.

Methods of hardening and staining.

The animals being killed by chloroform and bleeding, the remaining blood was washed out by injection of warm saline solution. After this, warmed diluted Müller's fluid or 1 $^0/_0$ potassium bichromate solution was injected. The cord was then carefully taken out and kept for one day in 1 $^0/_0$ bichromate or diluted Müller's solution and changed the next day for the full strength Müller or 2 $^0/_0$ bichromate. Subsequently for the Weigert stain the cords were kept in 80 $^0/_0$ alcohol.

The Weigert and the Marchi method of staining were employed, and also an experimental stain of my own. The results to be mentioned later are from sections stained by the two former methods only.

The Weigert method presents the difficulty in the decolourising to exactly a standard point, and the method exposes the section to many dangers before the cover-glass is laid on it. In examining sections the test assumed of a sound fibre, by this method, was the existence of a yellow spot indicating the axis-cylinder. For this purpose decolourisation by the old method is preferable to that of Pal, in which the axis-cylinders are made quite white.

The Marchi method, from its remarkably definite results and comparative celerity of application, has met with general favour, but apparently is also open to grave objections.

In those cases where there is any sclerosis this method is apt to be misleading, because scar-tissue stains like normal tissue and requires careful examination with a high power to distinguish it. Similarly the effects of traumatism must be excluded.

The most remarkable feature in the Marchi method is the amount of apparent degeneration which it shows in the normal cord contrasted with the fact that Weigert sections never show a degenerated fibre in a normal cord. It is true that a "normal" degeneration in peripheral nerves has been described by Mayer[1] and the same thing might be argued *à priori* for the cord. But the observation has never been confirmed; in the few experiments I have made in the same direction I have been unable to confirm it, and it is not the experience of teachers of physiology, who see a large number of sections in the course of their work, that degenerated nerve-fibres exist in normal nerves. The importance of this point will be apparent in connection with the anterior cornual lesions.

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[1] S. Mayer. *Prager Zeitschr.* 1881.

Special experiments showed that neither injection of the animal nor slight decomposition of the cord had any noticeable effect on the Marchi stain in the normal cord. But Tooth[1] has described an appearance caused by decomposition simulating degeneration in the Weigert method.

It may be that the fibres in the spinal cord like the peripheral nerves, vary to some degree in structure at different points. It has previously been observed that sections of peripheral nerves show some appearances somewhat similar to degeneration for a section or two in a series, but an examination of the whole series shows this appearance to be fallacious; and I can quite confirm this observation.

For scattered fibres as distinct from a tract degeneration I am inclined to prefer a pure osmic acid stain. Osmic acid was long ago recommended and used for staining the spinal cord, but not, so far as I know, for degeneration[2].

If a piece of cord after being hardened in 2 °/₀ bichromate for 14 to 21 days be cut in gum, and the sections be washed and then placed in 1 °/₀ osmic acid solution for 24 hours, they stain an uniform brown or black according to their thickness. When mounted, however, the degenerated fibres are found to be much more deeply stained than the normal ones. They can be made plainer by the following method:—after dehydration, the sections are placed in cedar-wood oil from $\frac{1}{4}$—$\frac{1}{2}$ hour (or a shorter time if the oil be warmed) and the excess of oil well washed out in xylol or naphtha. The cedar-wood oil decolourises the normal fibres far more rapidly than the degenerated ones which stand out black, with an indefinite swollen appearance as would be expected of a degenerating fibre. The indefiniteness of outline, however, makes the appearance very confusing in a tract degeneration. Both normal cat's and normal monkey's cord show no degeneration by this method. Over-decolourisation is not so easy as in the Weigert method but does occur by prolonged immersion in cedar-wood oil. Palladium chloride instead of osmic acid produces nearly the same result. The results are much the same as by the Marchi method except that there is not the appearance of precipitate so characteristic of the Marchi sections, and the total degeneration appears always somewhat less than by that method.

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[1] Tooth. *Gulstonian Lectures*, 1889.

[2] Flechsig. *Leitungsbahnen, etc.*, 1876; Exner. *Sitzb. der Wiener Akad.* 1881.

Degeneration after double section of cord.

Three monkeys' cords (cp. p. 369), in which degeneration had proceeded for six months, for one month and one week respectively, were examined.

In the first monkey's cord there was a slight difference between the two sides, since the lower division was not quite complete on one side.

There was a not inappreciable difference in the amount of degeneration in the three monkeys' cords. There was no evidence of excessive inflammation around the cord resulting from the operation. And I do not think the result due in any great degree to an alteration of the blood-supply, for an examination of the sections shows that the blood-vessels remained patent and contained blood at the end of six months. That the vessels running with the posterior roots of isolated piece were still functional was shown at the autopsy by the fact that the injection of the bichromate solution passed into them.

Speaking generally it may be said that six months after double division, sections show a peripheral band of absolute degeneration, wider posteriorly than anteriorly, but not sparing any part of the margin of the cord. It extends down, in wedge-shape, into the anterior fissure. The extent of this absolute degeneration is shown diagrammatically, in Fig. 1. ("Absolute" is used for when not more than about 2—3 % of the normal number of fibres remain.)

Taking the various parts more in detail:—The posterior columns are absolutely degenerated except where fresh fibres from posterior roots are coming in. Several fibres are apparently still in a degenerating stage, but there are very few indeed (six at most) which have the appearance of being good. Whether they are so throughout their length cannot be considered proved without longitudinal sections. The still degenerating fibres have no very definite arrangement, but their existence in this stage long after the majority have gone, points to their being of different function to the others. Even so the degeneration appears to be far more complete than after simple section of the cord. On combining the figures given by Sherrington[1] of ascending and descending degeneration we see that the absolute degeneration exists only about two-thirds of the distance towards the grey matter—close to

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[1] Sherrington. This *Journal*, Vol. XIV. 1893.

the substantia gelatinosa it is severe, and in the intervening piece considerable, but does not approach absoluteness. Hence I think that there are a certain appreciable number of fibres, belonging to the posterior columns, of greater length than two segments arising or ending in the cord along its length. Where they come from can only be a matter of speculation, but in some sections fibres can be traced nearly the whole distance from Clarke's column into the posterior column. The fibres of Clarke's column itself are all degenerated, but this is found too after simple section.

In the anterior and lateral ground-bundles there is very little degeneration,—this holds good for the whole length of the isolated piece. In the lateral limiting layer there appears to be a slight degeneration as we descend from the upper to the lower lesion. In the lateral column there is an indication of the isthmus of good fibres seen after simple section, and this is more marked as we ascend from the lower to the upper lesion. The possible origin of these fibres is discussed below. Otherwise the degenerations are much the same throughout the isolated portion.

Since both the cerebellar and pyramidal tracts are in the posterior part of the cord the degeneration here appears much more extensive, and the band of absolute degeneration becomes somewhat suddenly less rather in front of the central canal and is reduced from about one-third to one-fifth of the whole breadth of white matter.

There is a well-marked triangle of nearly absolute degeneration at the angle of the anterior fissure, which would scarcely be expected from a combination of ascending and descending degenerations as figured in Sherrington's[1] paper, although the degeneration along the lips of the fissure itself is perhaps rather less than might have been anticipated and does not run down quite so far, at any rate in sections near the lower lesion. It forms however a well-marked strip extending about two-thirds the way down towards the anterior commissure.

The most marked feature about the degeneration after double division is its comparative definiteness. Although there is naturally a considerable amount of sclerosis in the parts internal to the peripheral band of degeneration, very few still degenerating fibres are found. The normal fibres occupy a very large area of the cord, and since this area is not appreciably less near the lower lesion than near the upper one, and also because the course of posterior root fibres is pretty well known, it does not appear likely that the large number is due to the fact of two

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[1] Sherrington. This *Journal*, Vol. XIV. 1893.

roots entering the isolated segment in the sense of supplying such fibres, although it does not seem improbable that a functional relation may exist, and so the surviving fibres might be less if the isolated portion were smaller.

If we now turn to sections obtained from Case II., in which the monkey lived only one month, the state of things is rather different. The general distribution of the degeneration as shown by the Marchi stain is much the same, except that some degeneration seems to extend right up to the grey matter. On closer examination of the section, and particularly of sections stained by the Weigert method, it is seen that a very appreciable number of sound fibres remain in parts where, after six months, absolute degeneration is found, viz., right up to the periphery. This is seen also in the posterior column, where the sound fibres probably number quite one hundred, although I have not had the opportunity of actually counting every one. Although irregularly distributed they are, I think, most numerous near the median septum, and of course near the grey commissure. Naturally I have not included any due to a just entering posterior root.

The same is true of the other parts of the cord. Right up to the periphery, sound fibres may be seen. In the third monkey's cord the general distribution is the same as in the second, but the total amount is considerably less.

In certain areas Sherrington could find no trace of degeneration after simple section. These, as might be expected, were chiefly in close proximity to the grey matter. After double section a few degenerated fibres can be found in these positions and even in the islets surrounded by grey matter. In sections stained by the Marchi method the degeneration in these parts is even what would be called considerable.

The chief point of interest is that the total number of normal fibres remaining seems to be in excess of the number of nerve-cells contained in the isolated piece even without deducting anterior cornual cells. This would indicate a considerable amount of division in the fibres. The observation however does not rest on a numerical basis.

Degeneration after longitudinal section of cord.

Turning now to the sections, after longitudinal division of the cord, on examining those taken through the lesion, there is evidence of slight injury to the parts just surrounding the anterior fissure and in the grey matter on either side of the middle line. Of course there is also considerable injury to the posterior columns but none external to the posterior roots. (Fig. 2.) The wounding of the posterior columns does not affect the result, since they do not contribute fibres to any other part of the cord.

The amount of degeneration naturally varies with the extent of the lesion, hence it is not the same in the two cords. A short distance above the lesion, there is, besides the degeneration in the posterior columns, a patch of degeneration just external to the posterior roots, a rather scattered degeneration in the antero-lateral column about on a level with the anterior commissure, some degeneration above the anterior fissure, and a few fibres all along the periphery of the cord. (Fig. 3.)

As we ascend higher the degeneration in the antero-lateral column collects together (Fig. 4) and forms a small patch which can be traced up into the cervical region, and probably goes the same course as the rest of the antero-lateral tract, viz., to the superior vermis of the cerebellum[1]. Naturally these long fibres divided in the anterior commissure are not very numerous: so that although a few must have been divided in triple hemisection of the cord, Mott[2] found no degeneration in the opposite half of the cord.

The degeneration around the anterior fissure quickly diminishes: these fibres are chiefly short commissural fibres.

The degeneration in the posterior part of the cerebellar tract diminishes somewhat as we ascend the cord. It is probably due to the injury to grey matter, although well below the level of Clarke's column.

There appears therefore to be an ascending tract of fibres making up the anterior part of the cerebellar tract formed by fibres coming by the anterior commissure from the other side of the cord, not taking up their position at once but gradually working their way out to the periphery. They occupy a region at the periphery which corresponds fairly well to that of less complete degeneration in the monkey, after double transverse division of the cord. But as these fibres do not at once assume their peripheral position they become apparent as a tract only after ascending a few segments from the lesion.

Degeneration after anterior cornual injury.

It was observed in sections through the longitudinal lesion that there were more degenerated fibres passing out in the anterior roots than could

[1] Auerbach. *Anat. Anzeiger*, 1890.

[2] Mott. *Phil. Trans.* Vol. LXXXIII. B.

be accounted for by the injury to grey matter, for this was comparatively slight. The probability therefore existed that some fibres crossed over from one anterior or middle cornu to pass out by the opposite anterior root. This has long been asserted histologically, although no experimental proof has been put forward. I therefore attempted a lesion involving one anterior cornu only. Naturally the lateral column had to be severely injured, but the total damage was limited to the area between anterior and posterior roots. As the result, degenerated fibres were found, both in sections through the lesion and of the anterior root, on the opposite side to the injury; thus establishing experimentally an histological hypothesis. (Fig. 5.)

In sections above the lesion, degeneration is found on both sides of the cord in the cerebellar and antero-lateral tracts, but a patch just external to posterior root only on the side of the lesion.

The two experiments are therefore complementary to each other, showing that the anterior commissure fibres go in part to the antero-lateral column and at the same time derive their origin from the grey matter of the opposite side.

The main conclusions arrived at therefore also confirm Auerbach's observations after destruction of the posterior part of one half of the cord, as well as the experiments of Ehrlich and Brieger[1], and Singer and Münzer[2] on destruction of the lumbar grey matter by compressing the abdominal aorta.

It would have been more interesting histologically to perform the last two lesions on monkeys; and this I hope soon to have an opportunity of doing.

Finally a point previously observed[3] and corroborated by my experiments, is the very *local origin of the anterior root fibres.* In sections of anterior roots from the isolated portion, the upper root contained a few, the lower no degenerated fibres, although cut off from all communication above. This is in striking contrast to wide-spread connections of the posterior root.

Summary.

Double transverse section of the spinal cord at about three segments distance, in the lower thoracic region, causes in the isolated piece

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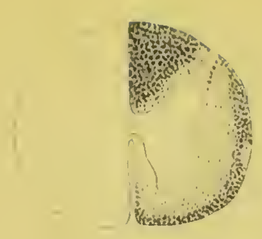
[1] Ehrlich u. Brieger. *Zeitschr. für klin. Med.* VII. 1884.

[2] Singer u. Münzer. *Wiener Sitzungb.* III. Abth. 1887.

[3] Sherrington. This *Journal*, Vol. XIII. 1892.



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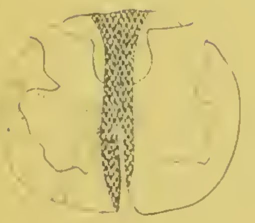

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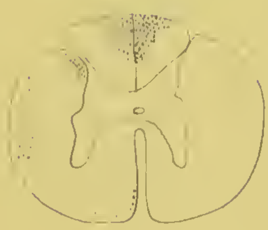

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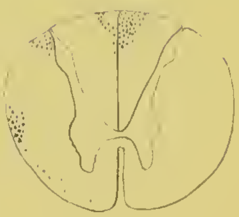

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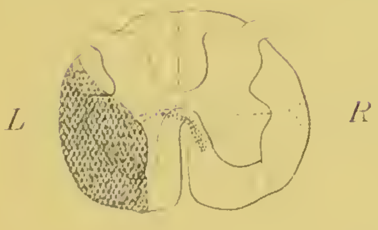

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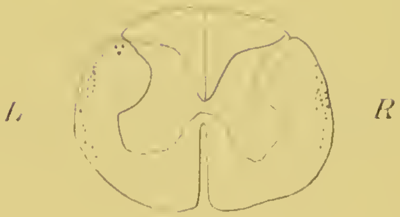

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Edwin Wilson, Cambridge

a very complete degeneration of the posterior columns, with a sharply defined peripheral band (of varying breadth) in the other columns, well illustrating the circumferential distribution of the long tracts.

The anterior roots coming off from the lower part of the isolated piece show no degeneration, so that their fibres have a very local origin compared with the connections of the posterior roots.

The degeneration in the isolated portion of cord was less at the end of one month than at the end of six months, so that apparently degeneration increases with time.

After longitudinal division of the cord, besides a tract of degeneration just external to the posterior roots, there is an ascending degeneration at the anterior border of the cerebellar tract.

Injury to the anterior cornu of one side of the cord causes a degeneration in the anterior root of the other side, so that some fibres of the anterior roots come from the opposite half of the cord.

The Marchi stain cannot as yet be accepted as yielding an absolutely unmistakable criterion for scattered degenerations.

For permission to use the Laboratory, as well as for much friendly advice and assistance, I am indebted to Dr Sherrington, to whom I take this opportunity of acknowledging my thanks.

PLATE XIV.

Fig. 1. Diagram to show degeneration about middle of isolated portion in double transverse division.

Fig. 2. Diagram to show lesion in longitudinal section (6th lumbar). Dotted lines to show direction of degenerating fibres.

Fig. 3. Diagram to show degeneration at 6th thoracic nerve root after longitudinal section at 6th lumbar.

Fig. 4. Diagram at 6th cervical nerve root after same lesion.

[Figs. 1—4. Degeneration (except in posterior columns) represented on one side only.]

Fig. 5. Diagram to show lesion to anterior and lateral cornua. Dotted lines indicating degenerating fibres. About 2nd lumbar.

Fig. 6. Diagram to show degeneration in cervical enlargement, after lesion in Fig. 5.